Project 2B
Great Salt Lake Synoptic Survey of Selenium in Water, Seston, and Brine Shrimp

CONTRACT WITH:	Parliament Fisheries
PRINCIPAL INVESTIGATOR:	Brad Marden
CONTRACT VALUE:	$95,033
SCHEDULE:	March 1, 2006 through February 28, 2007 (elapsed time: 12 months)

Project Objectives:

The project objectives are to:

1. Document the temporal and spatial characteristics of total selenium (T-Se) in water and correlate with seston and *Artemia* tissue concentrations.
2. Correlate isotopic ^{15}N and ^{13}C levels with T-Se in *Artemia* tissue.
3. Monitor primary production indicators and record *Artemia* population dynamics.

Please see Data Quality Objectives for Project 1B for further detail.

Background And Justification

The conceptual model of selenium flow in the Great Salt Lake, UT (GSL) ecosystem (Johnson, pers. com.) provides the framework for identifying essential components influencing the fate and effects of selenium in the GSL. The conceptual model also serves to identify data gaps in our understanding of selenium dynamics in the GSL. Project 2B aims to provide details necessary for one of the major domains in the selenium cycling model: trophic transfer of selenium upward through the food chain.

Detailed documentation of selenium loads in water, seston (suspended particulates and microalgae), and *Artemia* is a necessary and fundamental component for establishing a selenium water quality standard for the GSL. In terms of biomass, the aquatic zooplankton community of the GSL is massively dominated by *Artemia*. Using biomass conversion calculations for *Artemia* from Conte (1988), the GSL, at an elevation of 4197 ft above sea level, has an estimated *Artemia* biomass ranging from 231,000 to 575,000 metric tons. Due to their abundance in the GSL, and their high per-capita filtering capabilities, they represent a substantial biogeochemical processor of soluble and suspended nutrients and chemicals. Additionally, *Artemia* are an essential prey item for many species of migratory and nesting birds within the GSL ecosystem. Commercially harvested *Artemia* cysts are sold throughout the world as a food source for finfish and crustaceans reared in aquaculture settings. The GSL *Artemia* resource supports a 30 to 50 million-dollar per year *Artemia* industry. Each harvest season the industry removes between 2000 to 8000 metric tons of cysts and biomass from the GSL.

This removal from the system may be an important component in total selenium loads in the GSL. In short, the *Artemia* resource on the GSL is of critical ecological and economic importance. Any reasonable study of contaminants in the GSL ecosystem is obligated to include a careful evaluation of *Artemia* and the microalgae that provide the nutritional foundation for the *Artemia* population.

Selenium is a bioaccumulating toxin with the most probable pathway of exposure to avian species being the dietary route (Adams, et. al., 1998). The establishment of a GSL site specific water quality standard that is protective of wildlife (Clean Water Act, Section 304A) necessarily includes an assessment of the trophic linkages between water, seston (suspended particulates including microalgae), *Artemia* and birds (Byron et al., 2003). Project 1 (GSL Avian/Selenium Study) will document selenium loads in selected avian species and potential routes of exposure. Project 2B/Objective #1 is designed to complement the information obtained in Project 1 by identifying and quantifying selenium transfer between the open water of the GSL and *Artemia*, an important prey species of shorebirds and waterbirds.

Avian species of concern that exploit *Artemia* food resources directly are found primarily in aquatic gleaning, probing and diving foraging guilds. Notable species of aquatic/pelagic gleaners or divers that occur in very large numbers on the GSL, and that forage extensively on *Artemia*, include eared grebes (*Podiceps nigricollis*), red-necked phalaropes (*Phalaropus lobatus*), and Wilsons phalaropes (*Phalaropus tricolor*). Population numbers of these birds and ducks on the GSL at a given time can range from 150,000 to 700,000 birds. As an example of their population size on the GSL, maximum numbers of phalaropes, gulls, ducks, and eared grebes at any one period were 111,069, 219,679, 717,347 and 242,900 respectively (Paul and Manning, 2001). More than 50% of the North American population of Wilson's phalaropes and eared grebes utilize the GSL during their fall migration. During this time period they may increase their body weight by 45%-54% (Jehl, 1997). Much of this weight gain is attributable to the abundance of *Artemia*. Surface-feeding ducks and gulls also ingest copious quantities of *Artemia* at various times during the year. GSL breeding birds such as American avocets (*Recurvirostra americana*), black-necked stilts (*Himantopus mexicanus*), and California gulls (*Larus californicus*) that ingest aquatic invertebrates as a primary dietary component may represent high-risk species. These species are of particular concern due to the well-documented adverse impacts of selenium on avian reproduction (Heinz, 1989). Agricultural drainage basins and evaporation ponds located in Western States present a threat to many species of breeding shorebirds, but no current GSL study indicates population-level reproductive impacts on shorebirds. The potential for harm to breeding birds from selenium, however, remains a substantial concern.

Specific Comments And Strategies For Each Objective

Objective #1. Document the temporal and spatial characteristics of total selenium (T-Se) in water and correlate with seston and *Artemia* tissue concentrations.

Most studies suggest that the GSL is a chemical sink—that metals discharged into the GSL are rapidly precipitated and biologically unavailable. Concentrations of selenium in the GSL, even in areas near selenium inflow sources, are generally less than 20-68ug/l (Waddell et. al., 2002). Most open water assessments of the GSL indicate selenium concentrations well below these levels. Due to the high sulfate concentration, and the anaerobic deep brine layer of the GSL, selenium may remain biologically unavailable and at very low waterborne concentrations. The risk to wildlife from direct exposure to waterborne selenium is not presumed to present any significant risk. However, bioaccumulation and trophic transfer of selenium through prey represents a potential threat to avian species. Objective #1 is designed to provide a quantifiable evaluation of this risk throughout the avian breeding and migratory season on the GSL.

The correlation between waterborne concentrations of selenium and whole-body burden of *Artemia* tissue in the GSL has been evaluated previously. Brix et. al. (2004) found an acceptably linear relationship between co-located GSL water samples and *Artemia* tissue selenium concentrations. They also observed an inverse relationship between selenium concentration in water and its corresponding bioaccumulation factor. Although useful information was obtained from this study the temporal and spatial scale of the research was limited. In addition, the role of microalgae as a dietary route of selenium exposure was not evaluated. There remains a need to more thoroughly examine the correlation between water, seston (microalgae), and *Artemia* whole-body selenium loads across diverse GSL regions and over multiple months.

Objective #2: **Correlate isotopic ^{15}N and ^{13}C levels with T-Se in *Artemia* tissue.** Isotopic analysis has been shown to be a valuable tool for tracing nutrient and carbon flow through food webs. Isotopic nutrients convey an integrated picture of the diet of zooplankton over the course of their growth season. Changes in isotopic nutrient profile may indicate a shift in foraging opportunities and strategies among Artemia—it has been inferred by others (e.g., Gary Belovsky) that Artemia may exploit benthic microalgae during times of depleted phytoplankton. The USGS has documented a distinct temporal pattern of ^{15}N in *Artemia* tissue (Naftz, 2005). The ^{15}N level may be an indirect indication of shifts in diet composition and foraging strategies. It may also reflect nutrient pathways from tributary sources through GSL aquatic trophic levels.

According to the GSL/Se conceptual model there is a suggested link between selenium concentrations and ^{15}N in *Artemia* that warrants further investigation. Coupling Artemia tissue isotopic nutrient profiles, and selenium concentrations, with inflow source data for the same parameters should provide a better understanding of the linkages between nutrient and selenium sources and their transfer in the GSL food web. The inclusion of ^{15}N and ^{13}C analysis along with T-Se assessments may also allow investigators to prioritize inflow sources in terms of their role in energy and nutrient loading, utilization, and transfer. In essence, the isotopic nutrient analysis for this study is an inexpensive "add-on" that could provide valuable insight into trophic transfer of nutrients and selenium.

Objective #3: Monitor primary production indicators and record *Artemia* population dynamics. The purpose of this objective is to concurrently record *Artemia* population dynamics with measures of primary productivity and T-Se measurements. There are four compelling reasons for the inclusion of *Artemia* population data: 1) *Artemia* abundance is a useful measure of prey availability for avian aquatic foragers; 2) Population fluctuations in microalgae and *Artemia* may be linked to the temporal pattern of selenium in *Artemia*; 3) The additional effort and cost to provide *Artemia* population counts is small compared to the benefit of understanding seasonal biological dynamics on the GSL and utilizing this information for contaminant risk analysis, and 4) The biomass of *Artemia* and its selenium load may be a substantial component of the overall GSL selenium budget.

Scope of Work

Sampling Region

The Great Salt Lake receives inflow from ground and surface water sources. Inflow into the GSL is predominantly from the east—Wasatch Front river drainage basins. For the purposes of this study we define three regions of the lake for our research; each region is influenced by distinctly different inflow sources. Ogden Bay and the northeast region of Gilbert Bay receive water from Farmington Bay and Ogden, Weber, and Bear River drainage basins. In the southeast region of the GSL drainages from Tooele Valley, the Oquirrh Mountains, and overflow canals from the Jordan River provide the predominant inflow volume into the lake. This is also the region of the GSL in closest proximity to the drainage zone for Kennecott's outflow pipe. The central region of the GSL (north of Hat Island) is isolated from any specific surface inflow source and is primarily a mixing zone of currents from Gilbert and Carrington bays. Deep brines from Gunnison Bay (North Arm) of the GSL are channeled along a subsurface fault ridge (Allen Ridge) in this area of the lake. Due to the known differences in lake current characteristics and tributary influences among these three regions we have stratified our site selection to include representative sample sites from each of these areas.

Sample Site Location

Within each zone further stratification of sample site designation by depth and substrate is logical. Depth and substrate are known to have an influence on microalgal and *Artemia* population growth and abundance (Marden, unpublished). Deep sites of the GSL with an associated deep brine layer may be subjected to profoundly different geochemical cycling mechanisms than those associated with shallow or medium depth sites (Naftz, pers. com.). Light penetration and temperature factors also differ markedly between these sites and likely play an important role in biogeochemical dynamics.

It is preferable to have multiple randomly assigned sample sites within each of the depth and region designations. However, due to the budget constraints, Project 2B will limit the number of sites to the barest of essentials. Three sites will be designated within each region, for a total of 9 sample sites: three shallow (4190 ft. contour)/stromatolite, three medium (4180 ft. contour)/sandy; and three deep (4170 ft. contour)/unconsolidated mud sediments with known presence of the deep brine layer. All 9 sites will be sampled only during May and June. For the other months (July - October), one shallow and one deep site will be included in each of the three regions. The specific location of each site within a particular region and depth profile will be randomly selected. Rob Baskin of the USGS has completed an impressively rigorous bathymetry study of the GSL and has provided valuable advice with respect to site selection.

Frequency and Timing of Sampling

The sampling schedule is based on the following four goals: 1) collect samples prior to, during, and following characteristic shorebird breeding season; 2) sample during fall migration season; 3) collect samples within two *Artemia*/microalgal population growth and collapse cycles; and 4) include at least one sampling period during the final *Artemia* population demise in fall. This translates to an assumed total of 11 sampling trips. Extensive *Artemia* population data collected by the Division of Wildlife Resources (DWR) and *Artemia* industry research teams from 1999 to 2005 allow for reasonably sound predictions of the timing of *Artemia* population fluctuations. Very detailed and useful information is also available on shorebird and waterbird migration timing and breeding season (Paul and Manning, 2001). These information sources will be used to narrowly define the optimal sampling program necessary to achieve the goals listed above.

It is desirable to collect *Artemia* and seston samples within two population growth/collapse cycles because foraging strategies of *Artemia* may differ during times of algal abundance or paucity. The USGS has recorded a shift in isotopic ^{15}N in *Artemia* during the summer season (Naftz, 2005). This isotopic shift is likely attributable to changes in prey availability and composition and may be correlated with selenium tissue concentration in *Artemia*.

Sample Site Procedures

- Specific procedures will be detailed in subsequent SOPs
- The assumed number of samples collected and level of effort is summarized in Table 1.
- Temperature 0.5m below surface and at 0.5 m above bottom of water column.
- Secchi disk
- Dissolved oxygen
  - 0.5 m below surface
  - 0.5 m above bottom/chemocline
    - Collect and pool two plankton net tows from bottom to surface or above the chemocline in deep sites.
  - 165 um-mesh plankton net
  - 50 cm diameter
  - Thoroughly rinsed (outside of net) then with filtered water
  - Samples pooled & stored in acid-rinsed poly bottles (1000 ml)
    - Depth integrated water samples from the water surface above the bottom or above the chemocline in deep sites for Chl-A analysis.
  - Equivalent water volumes from 3 discrete intervals in the water column.
  - Water filtered through 125 micron sieve.
  - Samples stored in Amber Water Bottles.
  - Preservative added.
  - Samples stored on ice for transport to laboratory.
    - Depth integrated water samples from the water surface to the 0.5 m above bottom or above the chemocline in deep sites for T-Se analysis.
  - Fluorocarbon tubing
  - Peristaltic pump
  - Equivalent volume sampling at discrete intervals in water column (#intervals to be determined).

- Pre-filtering to remove zooplankton and large particulates.
    - 0.45 micron capsule filtration.
    - Samples collected in acid-rinsed poly bottles.
    - Acidification with nitric acid.
    - Pre- and Post-sampling field blanks.
    - All methods in accordance with those used by USGS.
    - Procedures and SOPs will use USGS, Nat'l Field Manual for the Collection of Water Quality Data, Book 9, Chaps A1-A9 (esp. Chap. A4) as a guideline.
    - Instructions for T-Se water sampling was received during March from USGS.

- Integrated water sample of suspended particulate matter (seston) from water surface to the bottom or above the chemocline.
    - Fluorocarbon tubing
    - Peristaltic pump
    - Equivalent volume sampling at discrete intervals in water column.
    - Pre-filtering, if necessary, to remove zooplankton and large materials.
    - Filtration and subsequent sampling procedures to be detailed in SOP.
    - Note: it is anticipated that during times of over-grazing of microphyte population by *Artemia* it may be unfeasible to obtain adequate sample quantities.

Artemia Enumeration and Primary Productivity Measurements

- Chlorophyll A
    - Filtration of known volume in laboratory
    - Homogenization with acetone extraction
    - Fluorometric analysis
- Artemia
    - Total samples filtered through 850, 500, 125 micron sieves
    - Sieve contents resuspended in known volume
    - Multiple sub-samples taken
    - Sub-samples counted
    - Age-class categories: Adults, juveniles, meta-nauplii, nauplii, cysts.
    - Counts in # organisms per liter

Sample Preparation and Shipping Procedures for Selenium Analysis

- Specific procedures will be according to instructions provided by analytical laboratory and/or CH2M HILL.

Data Base Format, Sample Tracking, Responsibilities

- To be provided by CH2M HILL

Deliverables (A detailed deliverable timeline is found in the annex)

- **Coordination.** Participation in study team meetings and conference calls on an as-needed basis
- **Data Quality Objectives**. (completed by 4/28/2006).
- **Workplan. I**ncluding scope of work, projects costs, project schedule, health & safety plan, protocols for collecting, handling, and shipping samples (completed by 4/28/2006).
- **Standard Operating Procedures.** Details of procedures and methods to be used for the collection and enumeration of samples.
- **Bi-Monthly Reports (4).** *Artemia* population dynamics, chlorophyll, Secchi, temperature, analytical lab results (selenium, ^{13}C and ^{15}N), and relevant comments or changes in Project 2B.
- **Six-Month Report:** Mid-year financial summary, *Artemia* population dynamics, chlorophyll, Secchi, temperature, analytical lab results (selenium, ^{13}C, and ^{15}N), and relevant comments or changes in Project 2B (completed by September 30, 2006).
- **Annual Report**: Year-end financial summary, discussion and conclusions, project plan for following year, *Artemia* population dynamics, chlorophyll, Secchi, temperature, analytical lab results (selenium, ^{13}C, and ^{15}N) (completed by March 1, 2007).

Assumptions And Critical Components

Quality Assurance

All work completed as part of this scope of work will follow UDWQ's Quality Assurance Plan protocol. Samples will be shipped to the laboratory selected by UDWQ following required protocol. Cost of laboratory analysis is not included in this scope of work.

Clearances/Permits

All necessary clearances/permits to complete the work specified herein will be acquired prior to and maintained for the length of the work. All access will be properly coordinated and permission obtained.

Safety

Safety is of the essence. Health & safety protocol will be identified prior to field work begins and followed.

Coordination

Parliament Fisheries will have the option to publish the results in the scientific literature. The UDWQ will maintain the right to review, critique, contribute to, and authorize release of any manuscripts that are being prepared.

Equipment

Vessels, vehicles, and laboratory space will be provided by the Utah Strategic Alliance Harvesting (USAH) group. Without their continued cooperation this project may not be possible or may result in significant delays or interruptions.

Laboratory Analysis

All laboratory analysis of selenium will be coordinated, funded, and organized by CH2M HILL.

Personnel

All personnel other than the P.I. are provided in cooperation with USAH. Therefore, the same concerns and limitations as previously mentioned in the equipment section above apply.

References For Project 2b

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GSL SELENIUM/CH2M HILL-CWECS
Project #2B: Synoptic Survey Pelagic Zone—Water, Seston, Artemia
Structure and Activities

1. Milestones, Deliverables and Schedule	**Year 1--- 2006**											
	April	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan 2007**	**Feb 2007**	**Mar 2007**
Activities and *milestones*												
1.1. Purchase equipment and supplies												
***Milestone**: Supplies and equipment delivered and all equipment operational.*												
1.2. Site visit / confirmation ofsite selection												
Substrate evaluated												
Depth and access confirmed / Equipment tested.												
***Milestone**: Precise location of all sites confirmed.*												
1.3. Pelagic sampling program												
Collection of Artemia samples												
Collection of Water samples												
Collection of Seston samples												
Milestone: Artemia population documented												
***Milestone**: Selenium analysis completed*												
1.4 Project #2B Bi-Monthly Results Summary												
1.5. Project #2B Scientific and Financial Reports												
1.6. Project #2B Year-two Project Proposal												
Deliverables	Equipment List, SOPs, Detailed Sampling Design		Bi-monthly Report: Artemia population, Selenium Analyses		Bi-monthly Report: Artemia population, Selenium Analyses	Six-Month Report: Financial Summary, Evaluation of Artemia, Water, Seston Results.	Bi-monthly Report: Artemia population, Selenium Analyses		Bi-monthly Report: Artemia population, Selenium Analyses		Final Report: Financial Summary, Evaluation of Artemia, Seston, Water Results.	Proposal, Budget, Sampling Program and Analysis for Subsequent Research.

PROJECT 2B
GSL/Selenium